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LEARNING UNFAMILIAR GROUND
- TERRAIN KNOWLEDGE FOR CONTINGENCY OPERATIONS -

BY

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United States Army

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ABSTRACT

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The end of the Cold War has ushered in an era of change in American foreign policy. America, nevertheless, will continue to elect to intervene militarily to advance or protect its global interests. Military forces, in the main, have been conditioned to expect suitable maps of the areas in which they will operate. With the increased likelihood that conflict involving American forces will occur on unfamiliar ground outside traditional threat areas, conventional mapping can no longer keep pace with requirements. Nonstandard mapping such as image-based products must become the norm, for support of training as well as for operations in the lower end of the operational continuum. Nonstandard maps and incomplete terrain data bases introduce significant changes into how combatants must be equipped and trained to learn unfamiliar ground. Furthermore, the mapping requirements process must be automated with advanced graphics and combatants must learn how to place effective demands on the system to get the support that will be available.

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USAWC MILITARY STUDIES PROGRAM PAPER

LEARNING UNFAMILIAR GROUND; Terrain Knowledge for Contingency Operations

AN INDIVIDUAL STUDY PROJECT

by

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THE FUTURE STRATEGIC ENVIRONMENT

The end of the Cold War has brought calls for a "peace dividend" payable to the American people; after all, America has always brought its boys home when the war ended. Voices of caution, on the other hand, argue that these are dangerous times in which to let down one's guard.

Being ready militarily means a great deal to America. When and if the United States commits its forces, it must win.

> "Incompetence otherwise might result in destabilized friendly governments, isolate them from the United States politically and economically, reduce U.S. access to crucial resources and sea lanes, deprive America of important privileges (. . .) and open opportunities for opponents to exploit resultant U.S. weaknesses."[1]

A key requirement for U.S. military forces will be knowledge of the terrain where they will operate. This section projects the likelihood of military conflict involving Americans over the next two decades, laying the groundwork for discussions of needed mapping support.

FRAMES OF REFERENCE

This paper arbitrarily adopts the terminology of the Joint Chiefs of Staff (JCS) for its operational continuum. In the operational continuum, military power may be used in war, conflict, or peacetime competition (now being referred to as forward presence operations). A fourth aspect, routine peaceful competition, does not involve military power.[2]

Without a superpower adversary, the U.S. will almost certainly not be in a global war in the foreseeable future. However, the U.S. could find itself engaged in hostilities with various regional powers in the future.[3] The lead time available to the mapping community as such threats develop and U.S. forces deploy should allow for surge production of standard products with existing assets. This paper focuses on crises at the lower end of the operational continuum; these are situations that are inherently difficult to support with mapping and that occur with alarming frequency.

HISTORICAL TRENDS

The U.S. has used military force over 300 times during this century. Although most of these incidents involved only military demonstration and show of force, the U.S. committed forces in low-intensity conflict well over 100 times. These commitments included 25 contingency operations in the 17 years since the end of the Vietnam War.

Since its entry into World War II, the U.S. has remained a major and permanent factor in international geopolitics. The U.S. experienced a surge in involvement in low-intensity conflicts after World War II that was tied to containing communist expansion and dealing with instability resulting from the breakdown of colonial systems. Over time, much of the American involvement in low-intensity conflict and peacetime competition came to be viewed in the context of the ongoing East-West confrontation.

When the Berlin Wall fell, many foresaw the demise of East-West confrontation and began postulating what the world would be like in the post-Cold War era. The literature abounds with concepts ranging from global peace to global chaos, from a isolated U.S. to an American global policeman, and from unipolar to multipolar concentrations of power.[4] Contemporary analysts appear, however, to promote or discard these options without much rigorous analysis of the factors that underlie stability or conflict in the world.

DESTABILIZING FACTORS

In the post-Cold War era, many factors contribute to unstable conditions that might lead to conflict. These factors, evaluated and weighed judiciously, should help us see just how dangerous our world really is.

The end of East-West confrontation is removing American and Russian controls over the behavior of former client states. The breakdown of the Soviet system is marked by chaos, resulting in sizable migration of emigres and refugees to Western Eu~ope and Israel. Longstanding hostilities, unsettled territorial issues, nationalism, sectarianism, separatism, and irredentism cause instability around the globe.[5] An international arms market offers increasingly advanced weapons to "rogue states," terrorist groups, and opposition or separatist movements. Human rights violations continue. International terrorism is a continuing threat to stability. Religious and communal tensions remain and often escalate to violence. Authoritarian regimes oppress their populations.[6] Africa faces ecological, economic, and human disaster on an unprecedented scale. Nations are beginning to blame each other for ecological abuse. Trafficking in illegal narcotics breeds violence in both producing and consuming nations.

STABILIZING FACTORS

Some factors, on the other hand, do tend to promote stability in the post-Cold War era. Although these are obviously sources for optimism, the optimism must be guarded.

America and Russia no longer need to spar through surrogate client states. The expanding global economy now links nations together with an interdependency that makes major military conflict virtually unthinkable.[7] Democratization, though fragile, is gaining in central Europe, the former Soviet republics, and Latin America. The United Nations gained credibility with its stand against Iraq and its commitment to peacekeeping in Yugoslavia and Cambodia. The Arabs and Israelis are discussing regional peace in the Middle East.[8] There is hope for some recovery and stability in the countries of central Europe.[9] The importance of ideology seemingly appears to be declining in international relations.[10]

PROJECTED CONDITIONS AND AMERICAN INVOLVEMENT

Weighing the relative importance of stabilizing and destabilizing factors on the international scene is difficult because the factors are linked. Some general trends, however, appear strong enough to serve as a foundation for projecting future international conditions.

Within the next decade, regional powers are likely to continue growing in importance. Central Europe will gain some economic vitality, and even the former Soviet republics will recover slowly. The plight of the very poor will continue to get worse in African nations with high population growth. Without the "stabilizing" influence of superpower patrons locked in an East-West confrontation, internal conflicts will run generally unchecked in former client states and risk becoming internationalized. Crises will continue to grip the world periodically through the decade, at the current rate or even more frequently. The U.S. must commit to a major effort to restore its decaying domestic infrastructure and may have to retrench some from international involvement.

In the following decade, with a strongly united and repaired Germany, Europe will make great economic gains and spur more powerful regional economic coalitions elsewhere. Africa will be in ruin. Crises will continue, but will shift geographically as changes occur in the world. The U.S., while still working hard on its infrastructure, should have begun its domestic recovery and started looking outward again.

During the East-West confrontation, the U.S. felt obliged to counter every Soviet move. In the wake of the Cold War, the U.S. has obvious breathing space in which to decide about intervening; it can and must refocus its strategy development process on regional issues, and is rediscovering the option it always had to exercise its political and economic elements of power rationally in the context of a country plan for each nation of interest. Decisionmakers and the U.S. public are growing increasingly aware that the U.S. has a choice about intervening.[11] They also recognize that the U.S., if it chooses to intervene, has a choice of means. Increasingly, the U.S. will opt for economic and political power, applied early at critical points, to reduce the need for escalation to military power. Even those openly critical of interventionism recognize the inevitability of continued instability in the world[12] and the continuing need for U.S. leaders to monitor the international geopolitical environment and to take steps to neutralize significant emerging threats.[13] The United States has shown it can and will act swiftly and forcefully, alone or with a multinational coalition, to contain or defuse threats to its interests. American decisionmakers must also respond within the context of political realities, which currently include a Republican administration and Democratic Congress, both flush from success in the Persian Gulf but facing a host of serious domestic issues. These same decisionmakers are also aware of the United States' acknowledged leadership role in the community of nations and of the stature of the U.S. within a United Nations that is growing more sophisticated and assertive in its approach to world issues.

Destabilizing factors heavily outweigh those for stability over the next two decades. In the more relaxed environment of the post-Cold War era, conflicts will sprout more easily. At the same time, methods for dealing with unrest will get more sophisticated, moving haltingly from *ad hoc* regional coalitions led by the U.S. toward collective security approaches. The U.S. will continue to straddle the fence between isolationism and internationalism, attempting to strike a balance between domestic and foreign policy. Although the U.S. will use economic and political means earlier and more adroitly, the counterbalancing rise in unstable conditions will, almost certainly, lead to continued frequent U.S. commitment of military forces.

ADJUSTMENTS IN CRISIS DECISIONMAKING

America faces a challenging period in the coming decades, protecting and advancing its global interests against fast-breaking, often unexpected threats. Success in military operations will increasingly depend on effective crisis decisionmaking at all levels.

EXECUTIVE DIRECTION

Unity in the U.S. military effort is achieved through a top-down process starting with the U.S. President. Since the Iran Contra affair, the Administration has kept tight control of the entire national security decisionmaking process and ensured that its policies are directly reflected in security decisions. George Bush's presidency has emphasized multiagency operations and combined military operations consistent with his "New World Order."

THE JOINT PLANNING PROCESS

Guided by the direction received from the National Command Authorities, the Joint Chiefs of Staff carry out their responsibility to give strategic plans and direction to the Armed Forces through the Joint Strategic Planning System (JSPS). The JSPS culminates in the Joint Strategic Capabilities Plan (JSCP), which guides the combatant commands in their preparation of plans for employment of the U.S. Armed Forces. The JSCP, responding to changes in the strategic environment, now addresses a wide spectrum of options for responding to a variety of possible crisis conditions in widely diverse geographic regions where U.S. interests might be threatened.[14]

Crisis onset can be met by "Flexible Deterrent Options" (FDOs), which respond to slow-building situations, "Deploy to Fight" reactions, which respond to crisis, imminent conflict, and conflict, and "Counter-attack", which responds to no-warning attack. The JSCP directs that combatant commands develop plans for military response in the following order of priority: Major Regional Contingency (MRC) plans, most-likely Lesser Regional Contingency (LRC) plans, concept summary for the second of two concurrent MRCs that develop sequentially, remaining LRC plans, and the Base Case Global Family of Plans.[15]

Although the JSCP notes that deterrence and crisis response require U.S. military forces that can respond quickly, prepared to fight on arrival from either the continental U.S. (CONUS) or forward-deployed locations,[16] it acknowledges the following:

> "The growing complexity of the international security environment makes it increasingly difficult to predict the circumstance under which US military power might be employed (. . .) we will emphasize peacetime engagement in pursuit of our national interests worldwide, increase the regional orientation of our plans, provide for as much flexibility as possible to enhance deterrence and warfighting capability, and provide multiple options to decision-makers."[17]

The JSCP provides the impetus to Commanders in Chief (CINCs) of Unified and Specified Commands to develop Operations Plans (OPLANs) and Concept Plans (CONPLANs) in the deliberate planning process. Implicit in the deliberate planning process is the recognition that an OPLAN or CONPLAN, even while under development, might serve as the nucleus for crisis action planning (see Figure 2, page 11).

Although a single CINC is charged with leading development of each OPLAN or CONPLAN, other combatant commands and the Federal agencies are involved in the process. "Of the ten combatant commands of the US Armed Forces in 1990, for instance, nine played major roles in the Gulf War, and the tenth (U.S. Southern Command, USSOUTHCOM) was affected. Six of these commands supported USSOUTHCOM in Operation JUST CAUSE in Panama."[18]

In addition to being combined (multinational) and unified (multi-agency), future operations outlined in OPLANs and CONPLANs will be joint (multi-Service). During these resource-constrained times, the Department of Defense (DoD) must reduce duplication of force structure. Services will all vie to improve their expeditionary capabilities and maintain force structure, so the Offices of the JCS and the Secretary of Defense (OJCS and OSD) must ensure that force structuring is complementary among Services and takes maximum advantage of specialized skills and low opportunity costs. Figure 1 (page 10) illustrates, in general terms, the joint force sequencing that is likely to emerge as a model for force application in OPLANs and CONPLANs.

A crisis is an incident or situation involving a threat to the United States, its territories, citizens, military forces, and possessions or vital interests that develops rapidly and creates a condition of such diplomatic, economic, political, or military importance that commitment of U.S. military forces and resources is contemplated to achieve national objectives.[20] In the past 30 years, over 200 world situations have met that definition of crisis.[21]

Figure 2 (page 11), adapted from the 1991 <u>Joint Staff Officer's</u>

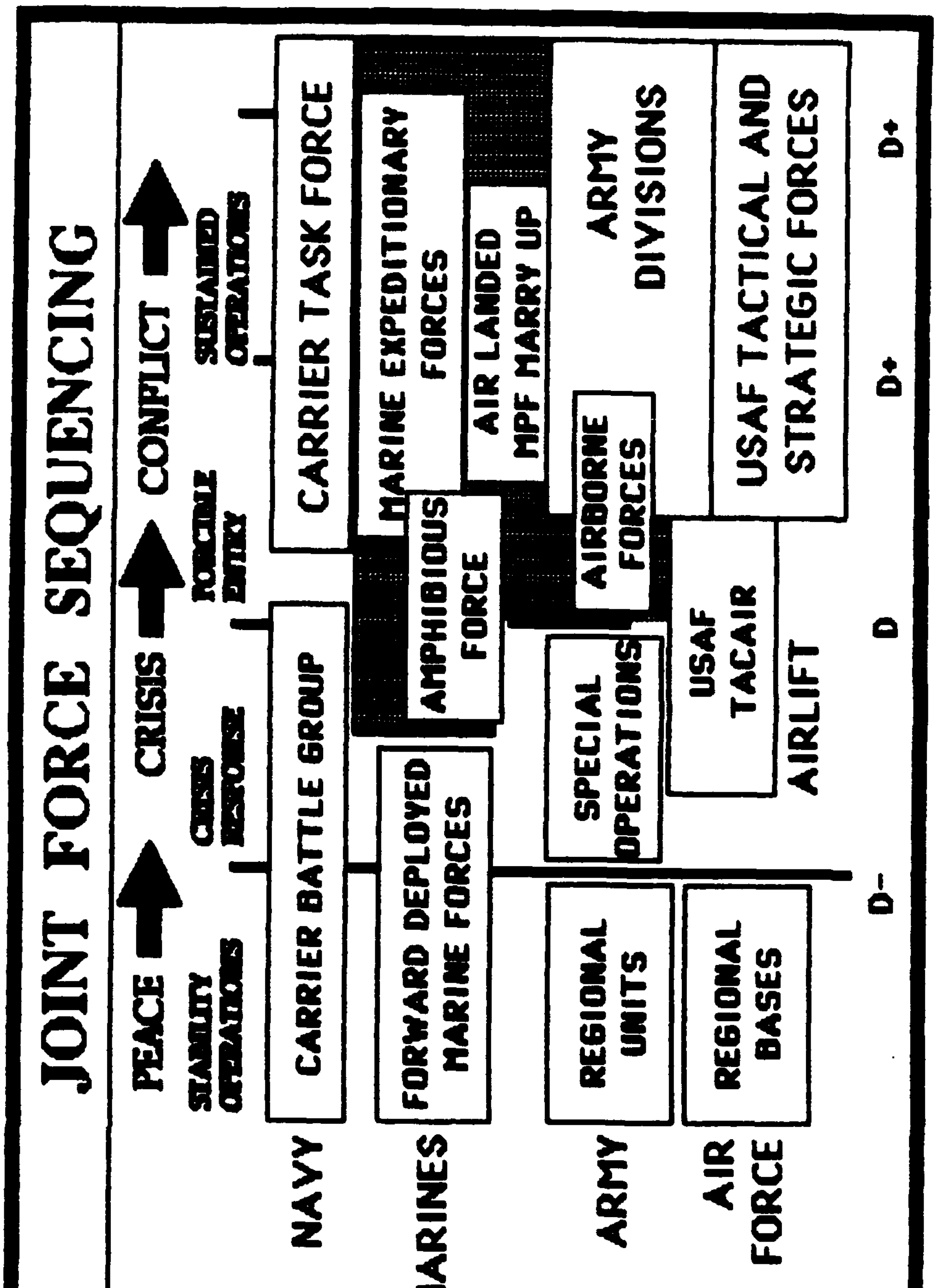

Figure 1. Joint Force Sequencing[19]

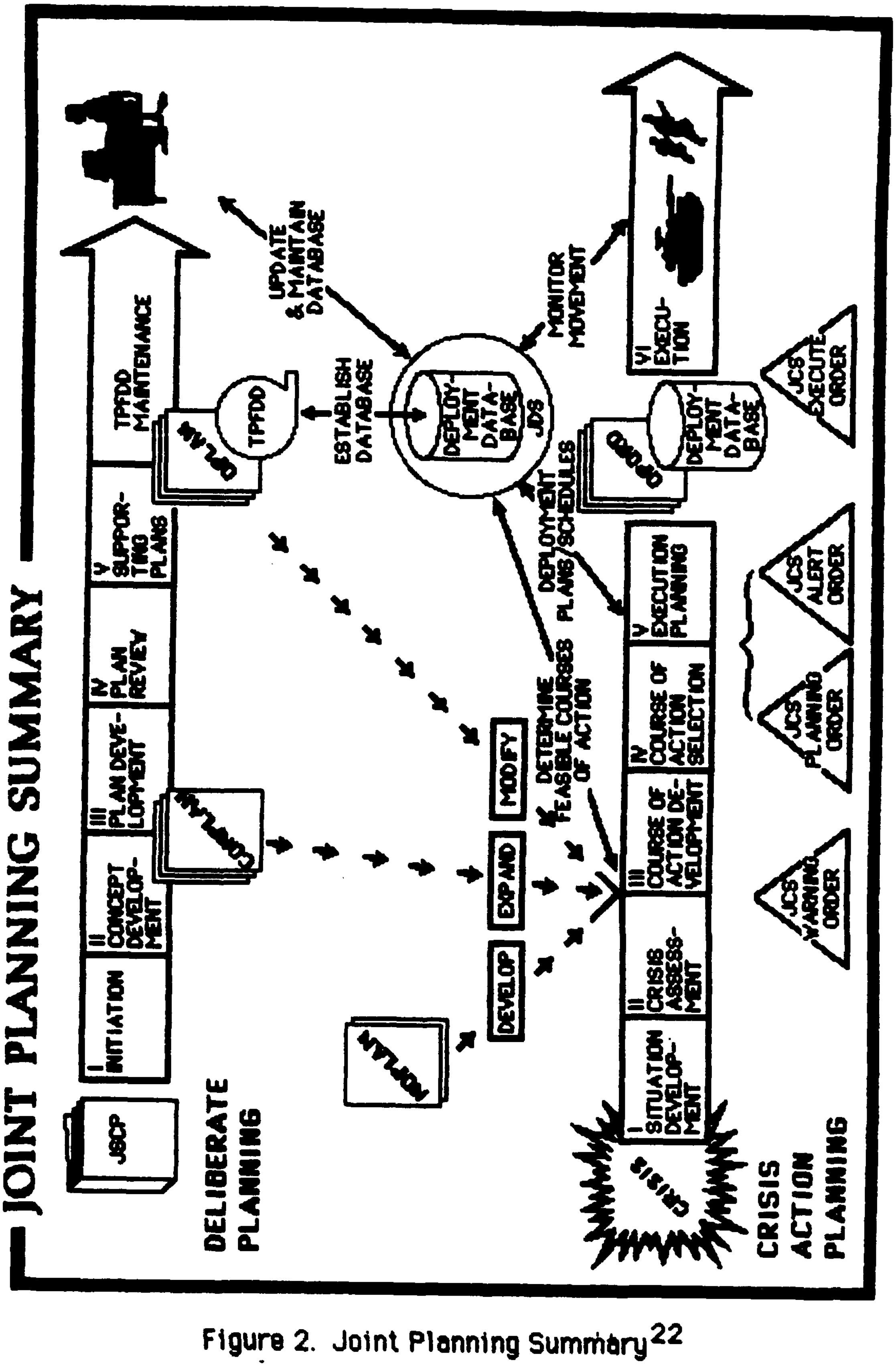

Figure 2. Joint Planning Summary[22]

Guide, outlines the linkage that now occurs, at least conceptually, between the deliberate planning system driven by the JSCP (top row in the diagram), with its investment of planning in CONPLANs and OPLANs, and what happens to the plans when a crisis is declared and perhaps escalates into conflict.

The Joint Operation Planning and Execution System (JOPES) provides the command and control foundation for monitoring, planning, and executing mobilization, deployment, employment, and sustainment activities in peace, exercises, crises, and war. Its automated modules supporting the planner or operations staff, however, do not yet include indices of map coverage or planning aids to register new requirements for map coverage. JOPES supports planning of forces, transportation, civil engineering, and medical support, but assessment of the adequacy of map coverage to support plans and the generation of coverage requirements for maintenance or new mapping remains an offline, mostly manual graphic (or tabular automated) process that is only now being converted into automated graphics.

Force mobilization and deployment, especially for the global scale of U.S. commitments, are such complex undertakings that planning to support them is itself complex and time-consuming. It will be years before the U.S. inventory of OPLANs, CONPLANs, and supporting databases is fully adjusted to the changes that have already occurred in the world, and even longer before campaign planning is complete enough to give clear pictures of the types of operations to be conducted on particular pieces of terrain. Planning of mapping, charting, and geodesy (MC&G) support to provide terrain knowledge for the force would be much easier if campaign planning were thorough and complete in peacetime; this, of course, is impossible.

"Campaign planning is done in crisis or conflict (once the actual threat, national guidance, and available resources become evident), but the basis and framework for successful campaigns is laid by peacetime analysis, planning, and exercises."[23]

The bottom line for the future is that smaller but agile, versatile, and lethal U.S. armed forces will be committed anywhere in the world on short notice. Planning, no matter how thorough and well-directed in peacetime, will never adequately cover all situations. Sufficient knowledge of the terrain to win, anywhere in the world on short notice, must be part of our military power of the future.

IMPLICATIONS FOR MAPPING SUPPORT

Clearly, the system providing terrain knowledge for military operations must be linked tightly into the planning systems and have the flexibility to adjust to crises. The links, however, have not always worked smoothly. The following excerpts refer to Operation Urgent Fury:

"In Grenada in 1983 --- seven months after President Reagan showed America on national TV a 10,000-foot, Cuban-built runway that he said might pose a potentially serious threat to hemispheric security --- the Joint Chiefs of Staff hadn't yet ordered to be printed one tactical scale map of the island (...) maps weren't even ordered from the Defense Mapping Agency until after midnight on Tuesday, 25 October, just hours before the 5:20 a.m. Marine assault on Pearls and Army Rangers parachuted on Pt. Salinas airfield."[24]

"The initial shortage of maps was eventually overcome by the short-fuzed production of 1:25,000 scale tactical maps by the Defense Mapping Agency

> (DMA) (. . .) these high quality maps did not arrive on Grenada until the operation was largely over. The unsatisfactory quality and quantity of tactical maps available during the planning, landing, and initial ashore phases of URGENT FURY was the most significant intelligence-related complaint from Marine units involved in the operation."[25]

Operation Urgent Fury prompted many changes in the processes of crisis decisionmaking and in the mapping community's linkage to joint crisis action planning. The situation had improved considerably by 1990, but there was still room for improvement. When the XVIII Airborne Corps deployed to Saudi Arabia in August 1990, tactical-scale mapping (at scales of 1:100,000 or larger) of the region, in response to standing requirements, had been focused on the region of conflict between Iran and Iraq; the only maps available of the deployment area had been produced in 1972 at scales of 1:150,000 and 1:200,000. The first products prepared at larger scales, simple enlargements of smaller-scale maps and crude image-based maps, were effective only as temporary expedients. Several months of force buildup elapsed before high-quality image-based maps could be made and rushed to the area by DMA and before in-theater topographic engineer units could be equipped with suitably advanced image processing systems and data bases to provide true combat mapping support in a fluid tactical situation.[26] Had Saddam Hussein continued his attack into Saudi Arabia in August or September of 1990, the forces opposing him would not have enjoyed superior knowledge of the battlefield.

As situations develop around the world and hotspots are assessed for their crisis potential, assessment of mapping readiness as an integral part of the crisis action planning process would help the U.S. capitalize on its technological advantages.

"The joint campaign should fully exploit the information differential, that is, the superior access to and ability to effectively employ information on the strategic, operational and tactical situation which advanced US technologies provide our forces. (. . .) Weather, mapping, charting, geodesy, oceanography, and terrain analysis are all areas where the joint force should achieve significant advantages."[27]

Because future operations will likely be combined, and because the U.S. is likely by virtue of its international leadership and technological superiority to regularly emerge as coalition leader, the U.S. military mapping community must take the lead in pressing for international terrain data structure, content, and exchange standards. Further, when Combined Task Forces (CTFs) are established under U.S. leadership the U.S. must quickly organize the field topographic engineering support that will accompany or be provided to the CTF.

As future operations will be multiagency, particularly during the situation development and post-conflict stabilization phases, the State Department, Central Intelligence Agency (CIA), Drug Enforcement Agency, and others must be closely tied into the military mapping requirements system, with appropriate priority to get their mapping needs met.

Since future operations will be joint, the support roles of field topographic engineering assets (such as terrain analysts) of the Army and the Marine Corps must be clarified. Military terrain experts could and should advise the entire force engaged in land combat, including close air support assets, but current allocation rules for topographic engineers are not based on joint missions. Formalization of joint support roles would affect not only structure but also employment doctrine, command and control relationships, and training.

The following section will detail what the MC&G community could do to maintain its technological edge and refine its requirements process to better meet the changing environment of crisis decisionmaking.

ADJUSTMENTS IN THE MAPPING COMMUNITY

In order to support an armed force that is committed globally to combined, unified, and joint operations across the operational continuum, the MC&G community must itself be creative, agile, versatile, and capable of focusing its energy on demand.

STRUCTURE OF THE SUPPORT SYSTEM

DMA was formed in 1972 from assets of the military Services, with the charter to meet the MC&G requirements of the Department of Defense DoD and to provide for the safety of navigation at sea. DMA has global responsibility for these missions except that it is responsible for mapping only military posts, camps, and stations within the territory of the United States; other U.S. mapping is the responsibility of the U.S. Geological Survey (USGS). DMA and USGS are headquartered within a few miles of each other in the Washington, D.C. area and coordinate extensively on production technology and techniques as well as on data and product standards. DMA is also the program manager for MC&G within DoD, and as such exercises considerable influence over the residual MC&G functions that remained in the military Services after 1972. In 1979, DMA assumed responsibility for military geographic information from the Defense Intelligence Agency (DIA), to which that function had been transferred after the Vietnam War.

Other federal agencies, such as the CIA and the DIA, have some limited capabilities to prepare small-scale maps and image-based maps for primarily internal use, and are building capabilities to extract terrain information from imagery.

Some of the Unified and Specified Commands are interested in acquiring capabilities to extract terrain information from imagery, primarily to assist in real-time assessment of feasibility to conduct contingency operations; the systems to do this, if acquired, are digital systems and are currently limited in their capacity to produce hardcopy products.

The most significant mapping assets available to the military, outside DMA, are those in the U.S. Army and Marine Corps. The Army has a topographic engineering force of four battalions (three Active Component and one in the National Guard), and the Marine Corps has a small troop structure of several platoons, focused primarily on beach survey and on terrain analysis. Service field mapping assets rely on foundation data provided by DMA and provide in-theater support with tailored products for exercises and combat operations. The Army's Topographic Engineering Center (TEC) at Fort Belvoir, VA, has a production capacity for general support terrain analysis and for maintenance of a worldwide water resource database. The Army, Navy, and Air Force all maintain research capabilities in MC&G; they focus research on Service applications of mapping technologies, but are also available to do research and development in support of DMA if required.

TRADITIONAL MAPPING SUPPORT

Since before World War II, maps have been made from stereo aerial imagery. Imagery provides both the geometry for placement of features on maps and the identity of those features. The tools of mapping are now so precise that they introduce 50 meters or less of error into the basic compilation of well-defined features on large-scale maps. When features are symbolized and symbols are shifted around to make the map more legible, another 50 meters of error can be introduced. When the map user introduces yet another 50 meters of error, the cumulative error in positioning can be 150 meters (about the width of a mark from a grease pencil at map scale) for coordinates read from a 1:50,000-scale map. See the Appendix for a more detailed treatment of map error. The amount of error increases significantly for smaller-scale products. In the old days, when positioning came from maps in the first place, these errors were absolute errors, not relative errors, and did not affect operations or trust in the maps very much. Positioning errors of less than the width of a grease-pencil mark on the map could be tolerated, and artillery could be walked in on a target from a safe start point away from friendly forces. There is, however, a shock lurking in the new positioning technology for both the user and producer of traditional maps; this will also be discussed in the section on adjustments by the combatant.

Offset lithographic printing was found, long ago, to be the only technology that could, at reasonable cost, produce many accurate copies of maps. Maps could flow in the tens of thousands per hour once a press was set up, but set-up alone could take an hour, even to print just one map. Because some quantity of any given map is always needed for planning purposes, the idea of making but not printing maps until needed never caught hold and the logical solution, followed to this day, was to go ahead and print war reserve stocks of a sheet along with the smaller quantity of operational stock for planning and exercises that might be consumed before the map became obsolete and had to be remade. This approach to map stockage generated vast piles of printed maps that would never see the light of day (i.e., that would sit in storage until obsolete) and would require both storage and stock management until retired from the system.

During a period of relatively stable threats, such as the Cold War, the cost and inefficiency of this system was perhaps justified; maps could be printed in bulk, shipped to forward depots by relatively inexpensive sealift when time was not a factor, and be kept available for use against the threat of massive, short-notice attack over known avenues of approach. The demise of the Warsaw Pact and the increasing probability of commitment of forces in unexpected geographic areas, however, promise a shock to the old notions of war reserve stocks of maps.

The first digital MC&G products entered the inventory to support simulators, trainers, and mission rehearsal systems that could afford fixed installation of the huge computers then required to use terrain data. As computing systems grew in sophistication and got smaller, digital MC&G products moved in to support weapons systems and are becoming commonplace on the battlefield. DMA is converting to digital production processes to take advantage of both digital imagery and the economies of automation. The military mapping community is on the threshold of geographic information systems (GIS) technology, and is making progress on defining standards that will help battlefield interoperability. The Appendix describes the status of digital MC&G in greater detail.

FACILITATING TECHNOLOGIES

As mentioned previously, imagery is the foundation for terrain knowledge furnished through maps. Security access restrictions, particularly imagery from high-resolution or exotic (non-optical) sensors, can be particularly troublesome to a field commander.[28] The highest-resolution civil imaging system, the French SPOT system, has a 10-meter resolution. The commercial provider Soyuzkarta (from the former USSR) sells imagery of 5-meter resolution from military sources.[29] DoD would like to see imaging at 5-meter resolution on the U.S.'s future Landsat systems.[30] These are close to the practical limits, given today's technology, for resolution that can get by without security restrictions; anything with higher resolution is provided by highly-classified collection platforms. High resolution also brings a price in the form of reduced ground coverage in each image.

Mensuration (or measurement) to give height, length, width, and areas of imaged objects can be done on virtually any space imagery for which sensing system characteristics and satellite location and attitude were recorded. Precise measurements, particularly for databasing purposes and for targeting, are a particular strength of DMA in its support to the warfighter.

Multispectral imagery (MSI), described in more detail in the Appendix, is a type of imagery that offers great promise for data extraction and expedient map production in support of crises. The Landsat Image Map (or LIM) offers particular promise; LIMs to a scale of 1:100,000 were prepared in one long weekend (Friday to Tuesday) recently to support evacuation of noncombatants from Haiti.[31] To effectively use MSI, however, DoD must promulgate a policy to effectively control procurement, duplication, use, and storage of the data; DoD must also standardize LIMs so that users can become familiar with them and introduce them into training.

Surveying and positioning, which involve establishing locations with respect to a geometric foundation, are rapidly being taken over by space systems. Geodesy, or determination of the exact shape of the earth, is now derived almost exclusively from analysis of satellite orbits. With this support, a field commander can be assured that the geometry will be right for systems fired from one mapsheet to hit targets on another. Space-based position/navigation aids are probably the most dramatic recent advance in positioning. By 1993, the Navigation System Using Time and Ranging / Global Positioning System (NAVSTAR/GPS) will permit very precise self-location and navigation. Hand-held and platform-mounted NAVSTAR/GPS receivers revolutionized positioning in the 1991 Gulf War, and offer many possibilities discussed in more detail in the Appendix.

As NAVSTAR/GPS helps in the delivery of precise fire, demands will increase for precise positioning support to targeting. The most accurate target coordinates must be developed by DMA in its baseplants. The next best source, and one available in the field, is the Analytical Photogrammetric Positioning System (APPS), which precisely measures positions on hardcopy imagery data bases called Point-Positioning Data Bases (PPDBs). DMA has supported APPS with hardcopy PPDBs from its aging Mark-85 production base; this support will be phased out as DMA moves to totally digital production, and the Services must adjust to new digital or video PPDBs. These field-portable systems deliver much more precise target positions than do maps, and will be the workhorses in target shops for future contingency operations.

Imagery offers the military force not only positioning information but also a wealth of information about surface materials and configuration of potential battlefields. Terrain feature extraction from imagery has been a traditional role of DMA, but technology now allows some of this work to be done in the field against immediate requirements. TEC has the Topographic Information Extraction System (TIES) under development for such work. The Appendix describes TIES in more detail. DIA and CIA are in the process of receiving TIES, and USSOUTHCOM is in queue for the system;

briefings to U.S. Special Operations Command (USSOCOM), U.S. Central Command (USCENTCOM), U.S. European Command (USEUCOM), and other commands may yield even further requirements in the field for data extraction systems.

Proliferation of TIES in the field raises an immediate issue; in 1987 the Joint Requirements Oversight Council (JROC) tasked DMA to develop families of standards that would also cover quality coding of digital MC&G data. DMA has not yet produced general standards for currency, reliability, and positional accuracy of digital data about the terrain, relying rather on the quality standards for its own line of digital products. General standards are needed now, and should force capture and storage, along with terrain data, of the date of information and whether the data came from combat reports, was validated on imagery, or was verified on the ground.

Digital scanning and printing, related technologies that are advancing very rapidly, offer tremendous potential throughout the MC&G community, particularly for the quick-response requirements of crises and contingency operations. The Appendix discusses digital scanning and printing initiatives in some detail. The current focus is on off-the-shelf bubble-jet printers; the Army had three of these machines in use following Operations Desert Shield/Storm, and is considering putting one in each topographic engineering battalion. The future for field use, however, probably belongs to electrostatic scanner/printers. Digital scanning and printing technology is very competitive with offset printing in mapsheet cost and clearly has the edge for quick response.

The Compact Disc - Read Only Memory (CD-ROM) has emerged as the *de facto* standard media for digital MC&G data when broad distribution, data integrity, and media durability are desired. CD-ROM offers high data density, reliable data transfer, no degradation of data from x-raying or other electromagnetic disturbance, low cost of both media and drives, and steadily falling costs for mastering. The fact that the user cannot alter the data on the disc, a benefit for data integrity, need not be a deterrent to data currency in the field; update data written on magnetic disks could be merged readily with data from the CD-ROM during field use, and keeping the two separate in the field would ease the necessary task of communicating necessary data changes back to DMA.

The presence of digital scanner/printers, computers, and high-capacity digital storage devices in topographic engineering units would help solve some current technical problems with map reproducible materials ("repromat"). Repromat currently consists of cumbersome pieces of mapsheet-sized film, at least one for each color or each mapsheet, that require continuous climate control. Building extra sets from a theater master set for deployment during contingencies is expensive and slow. Scanning repromat and reconstructing it when required during operations, discussed in more detail in the Appendix, offers considerable promise.

Electronic maps, or pictures of maps in digital form, offer significant advantages over paper maps in accessibility, speed of retrieval, and ease of use in certain field applications. The Program Executive Office -- Command and Control Systems (PEO-CCS) is building digital map backgrounds, line-of-sight analyses, other terrain evaluation, and three-dimensional visualization into the Army Command and Control System (ACCS); this initiative is described in more detail in the Appendix.

The ongoing ACCS development of electronic map capabilities saw its first combat application in Operation Desert Storm, when the Maneuver Control System (MCS) was used successfully with an enhanced electronic map background, with overlay capability, by the 1st Infantry Division.[32] Terrain modeling, analysis, and visualization were also successfully used in combat during the Gulf War in other systems discussed in more detail in the Appendix.

Terrain visualization, of course, can be a powerful tool off the battlefield, supporting training, planning, and mission rehearsals.

> "During simulations, portions of the globe can be graphically reproduced in great detail. Aircrews can see terrain, buildings, and targets with nearly the same visual cues they would have on an actual mission. The same is possible for troops on the ground. Systems similar to the Simulation Network being developed by the Defense Advanced Research Projects Agency may provide a cost effective training tool (. . .)"[33]

The Simulation Network (SIMNET) developed revolutionary technology linking large numbers of low-cost simulators for force-on-force training. Its success with relatively primitive digital terrain data led to spin-off initiatives to create more realistic "living map" simulations. The Defense Advanced Research Projects Agency's (DARPA's) Odin Program, for instance, creates a simulated environment that would allow the staff and commander to see the battlefield in three dimensions, as they would in battle. Odin and a number of other simulation systems useful in training, analysis, war games, and models are discussed in the Appendix.

When simulation systems are loaded with "real data" to support operations, they become mission rehearsal systems. Mission rehearsal systems such as the Automated Mission Planning System (AMPS), the Special Operations Forces Aircrew Training System (SOF-ATS), and a variety of

Air Force aircraft-specific flight simulators such as the F-117 and B-2 Weapon System Trainers (WSTs) offer great potential for ensuring the success of complex military missions, particularly over unfamiliar terrain.[34]

At the tail end of the MC&G production process, where the rubber meets the road in getting the finished products to the user, a major technological opportunity exists with barcoding. Logistics systems throughout DoD are switching to barcodes to simplify ordering, inventories, stock management, and shipping at all levels. The mapping community, however, has been slow to apply barcoding technology or convert to standardized stock numbers. Appendix A discusses, in more detail, why these changes must be made now.

SUPPORT TRENDS

DMA is centrally resourced to meet the MC&G needs of the Services, and as a general rule does not charge for its support. Despite trends elsewhere in DoD toward industrial funding of support activities, it is unlikely that MC&G support will begin to appear on the budgets of combatant commands. Central resourcing of DMA guarantees economies of scale in a production system that requires massive initial investment to function at all. Experience over the first two decades of blossoming digital MC&G technologies taught the U.S. military that contractors could, indeed, deliver impressive prototype data sets and exploitation systems at attractive costs. The rub came, however, in moving from prototypes to operational capabilities; building operational data sets over large geographic areas by hand-jam methods would be prohibitively costly and time-consuming, and no data exploitation system could use data tailored for another system. To nip these difficulties in the bud, Program Decision Memorandum 85 (PDM-85) was issued with the provision that the military Services would identify any unique MC&G support costs of systems they had under development and transfer those funds to DMA; the result was an immediate cutback in experimentation with unique data sets, bringing a greater measure of responsibility to new developments.

A possible exception to the centralized funding approach may be purchase of MSI. Under current rules for the sale of Landsat data by the Earth Observation Satellite (EOSAT) Corporation, a major combatant command like USEUCOM could purchase a single set of MSI and duplicate it for internal use but DMA, as the purchaser for DoD, could not purchase one set and make a copy for its own use before sending the original on to USEUCOM. Unless the rules for duplication and use of Landsat data are changed, it may become necessary for combatant commands to establish a budget item for purchase of MSI in their areas of responsibility for use in crises.

DMA's production capacity after conversion to its Digital Production System (DPS) was sized to support the Cold War level of MC&G support to strategic systems, high-priority work that has consumed the lion's share of production since DMA's inception. Standdown of significant portions of U.S. strategic systems, along with reductions in warheads, should eventually lead to shifts in DMA workloads. That would be good news for MC&G support to conventional operations, offering a windfall production capacity, were it not for the likelihood that reductions in strategic support missions will be coupled with additional reductions in overall funding of DMA. When these challenges come, DMA must be prepared to articulate increased support requirements from the users for contingency operations. Much could be done even in the narrow area of targeting, as suggested in the following:

> "The traditional (targeting) process, developed in the 1920/1930's Air Tactical School, works against countries that would be involved in conflict at the mid to high end of the conflict scale (. . .) as a result of this priority and limited collection assets, the data bases and target materials for LIC operations elsewhere, in the necessary detail to support the increasingly sophisticated weapon systems, are not available."[35]

During Operations Desert Shield/Storm, DMA found that most of its on-the-shelf map stockage of Saudi Arabia and Kuwait, including war reserves, was out of date. DMA went into a crash program, and discovered that it could make a lot quickly and could also move a lot quickly by brute-forcing transportation. Intensive management of individual shipments however, even though it successfully moved essential maps, had to displace movement of some beans, bullets, and guns. This experience may once again prompt consideration of surge printing within the theater of operations with prepositioned presses and with stocks of blank map paper (which does not suffer from obsolescence like the printed map). An alternative, suggested earlier, may also lie in eventual proliferation of digital scanner/printers that are competitive in per-sheet cost with offset printing and can make map copies on demand for immediate consumption. Some combination of centralized printing by DMA of planning and operational stocks of new map sheets, surge printing on demand in theater for major contingencies, and distributed copying within deployed formations is likely to emerge as the most efficient and responsive way of dealing with the full operational continuum.

The military Services must also review their organization and doctrine for topographic engineering in the new global situation. The Army has acknowledged the following as it approaches publication of a master plan for topographic engineering:

> "Support to immature theaters is more demanding since the availability of current maps, terrain and survey data bases and the time to produce products in most cases is limited. The use of remote sensors, rapid production of image maps, and digital data will ease these limitations."[36]

Other needed advances in field topographic engineering, all of which are technologically feasible, include fully mobile topographic engineer units that can move in one lift and keep up with the combat force, compact equipment with low physical and electronic signatures, good combat communications systems, and capable equipment that can be operated and maintained by small crews. Topographic engineers in the field must be linked laterally to each other to exchange data and vertically to DMA to provide value-added feedback. Regardless of how terrain data enter battlefield systems, the topographic engineer and the MC&G structure backing him up must be the terrain expert, the ultimate font of knowledge about the physical state of the battlefield. He must push this knowledge, within his geographic sector, to all who need it as well as keep the channels open for users to request specific support or information. As part of his terrain expert role, he must be able to advise the command on the accuracy, reliability, and survivability of positioning systems ("from maps to APPS") and provide precise positioning support when required.

CHANGES IN THE REQUIREMENTS PROCESS

The MC&G support structure can be only as good as the system that tells it what support it must provide. Significant changes are underway in how MC&G requirements are established for standing requirements world-wide and for support of rapidly-developing situations.

Until 1991, commands and agencies supported by DMA stated their geographic area requirements for standard DMA products on a regular bien-nial schedule. The summer 1991 submission will be the last to occur on a regular schedule, and will serve as the baseline for requirements changes to be submitted as needed in the future. For many years, area require-ments were submitted as manual annotations to global coverage graphics; this proved to be awkward and programs were started, both by command-level and DMA initiatives, to automate the process. The first efforts in-volved simply automated tabular listings by DMA stock numbers; the stock numbers could be cross-walked to automated graphics only at the DMA lev-el, still leaving the improved system somewhat unfriendly at the user lev-el. Recognizing this shortcoming, DMA is now working on Macintosh-based graphics to assist the commands and agencies in submitting changes to their area requirements.

With all the work going on in streamlining the area requirements process, however, the process remains peripheral to the mainstream of deliberate and crisis action planning in the commands; MC&G officers on the staffs of the unified and specified commands still must interface with planners and submit mapping requirements as a separate activity conduc-ted with DMA.

There could be a better way. JOPES does not now have any MC&G status and requirements module. Were one to be developed, DMA could put current map coverage and adequacy information on line to any planner through the secure Worldwide Military Command and Control System (WWMCCS) network, the planner could get an immediate feel for the terrain knowledge risks inherent in his planning options, and the command or agency could place new or revised area requirements, with appropriate priorities, directly on DMA through WWMCCS.

JCS Memorandum of Policy 31 (MOP-31) establishes the priority rules under which commands and agencies submit area requirements for MC&G support.[37] MOP-31 is undergoing revision because of the changed threat and global situation; DMA wrote a new draft that is being staffed with the unified and specified commands before input to JCS for approval and promulgation. The revised rules tend to establish priority on the basis of danger, with precedence within priority based on probability of occurrence;[38] there is now enough "wiggle room" in the system for commands and agencies to move their Third World mapping, if they wish, into sufficiently high priorities to assure prompt attention.

The geographic area requirements system drives DMA's multi-year production program for standard products; the changes noted above will make the program more responsive to developing situations outside traditional threat areas, but cannot meet the demands of crises and short-notice contingency operations. DMA has had a crisis action system for many years, but has recognized that the changed world environment now requires change to that system as well. The changes involve creation of a Country Precedence List and plans to develop Country Books, Starter Sets, and Current Operations Packs, all discussed in more detail in the Appendix. These initiatives will give DMA a significant head start on production for crises and also support CINCs' short-term requirements for mission planning, mission rehearsal, and the initial states of execution of military operations.

NEEDED ADJUSTMENTS BY THE COMBATANT

FAMILIARITY WITH MAPPING SUPPORT

Like any other specialty with a long and distinguished history of service within the military, mapping has developed the jargon and "secret handshakes" that mark all professions. A newcomer to the world of military mapping or an outsider looking in can become overwhelmed quickly with knowing, mysterious, and obviously very important references to things like geoids, ellipsoids, absolute and relative error, orthographic rectification, and obliquity of the ecliptic.

The water really isn't so bad once you're in it - - many from various backgrounds, late in their careers, have adjusted to mapping-related jobs and become pillars in the profession. The point for the combatant, though, is that he should not have to learn the language or ways of the mapper to get what he needs from the MC&G community and know how to use it well. The mapper, instead, should be coming to him and speaking the combatant's language.

DMA, like other defense agencies, has not only a capable core of active military personnel but also a large number of civilian employees with prior military service. DMA can talk the language of the combatant well, and has an active program of sending some of its most highly-qualified personnel to the Unified and Specified Commands as DMA liaison officers. These liaison officers work closely with the MC&G staff of the commands and provide an efficient channel for the command to get information or resolve support issues.

In addition to the DMA liaison officers, the Unified and Specified

Commands and most Service components of those commands have MC&G staffs to work mapping support issues, assist in the preparation of MC&G annexes to OPLANS and CONPLANS, and participate in the geographic area requirements process. These MC&G staffs tend to be tucked away in classified vaults, generally in J-2/G-2 shops or in the engineer special staff. They recognize, however, that MC&G supports the entire force; there isn't a battlefield function that doesn't rely in some way on knowledge of where you are, what is around you, and how it affects your mission. If the command MC&G officer and the rest of his staff are unfamiliar faces in the operations and logistics staffs, something is wrong. Command MC&G officers from all the Services attend special preparatory courses at the Defense Mapping School (DMS) in Virginia, so dynamic staff support should be the norm.

Depending on the Service, geographic area, and level of command, there may or may not be field topographic engineering support directly available. Support relationships and mission priorities for the topographic engineers in theater are established by the owning command within doctrinal guidelines; generally there should be a mix of direct and general support such that, by using that command's prescribed system, anyone with legitimate requirements for tailored MC&G support can get them satisfied. Field topographic engineers have technical support channels back to DMA, giving great depth to the support available.

CAPITALIZING ON CAPABILITIES

The mapping support available to U.S. military forces is the best in the world. Unfortunately, "best" is a relative term. As state-of-the-art pushes forward, there will always be some residual in the system from older, less capable technologies and procedures. When the potential geographic area of commitment is so obscure that native-edition mapping must be used, the combatant must be particularly wary.

One area that should be of particular concern to combatants in contingency operations is the business of maps, charts, and digital MC&G products prepared with different horizontal and vertical reference systems. Even when Universal Transverse Mercator (UTM) grids are on the maps, signifying to most users that they are using military maps, a single point could have several "correct" coordinates. Because the earth is lumpy rather than spherical, mathematical models or ellipsoids were built that defined surfaces or datums that best fit the general shape of the earth in a region. Eight datums of the hundreds used around the world found common use on older maps that are still in the military system; horizontal shifts of 305 to 1,900 feet occur between these datums and the World Geodetic System (WGS),[39] which is used for newer maps and for all digital MC&G products that come from DMA. Clearly, if all the maps and digital data for an operation are on WGS, everything should be fine. If not, problems can occur. For instance, coordinate errors between modern navigation systems and old targeting materials based on other datums are believed to have contributed to poor results with airstrikes and with battleship shore bombardment during operations in Beirut, Lebanon.[40]

For over four years, targeteers and MC&G officers have been cycling through a special DMS course on targeting errors. Some commanders and other staff personnel have attended these classes as well, but not enough to give any assurance that the force as a whole is alert to the problem.

When the operations order for a contingency operation is prepared and maps to be used in the operation are listed, the author of the operations order should ensure that all products are based on WGS. If they are not, that fact should be highlighted in the operations order and all combatants should be instructed to identify the datum (which is listed on each mapsheet in the legend) along with any coordinates they give. Targeteers, fire direction systems, and even the ubiquitous hand-held GPS receiver can make adjustments.

Even with the geodetic foundation right, errors of 150 meters or so can easily occur in coordinates read from 1:50,000-scale Class A line maps; 50 meters comes from the compilation itself, 50 meters from map reading, and 50m from displacement of symbology in the map.[41] One message is immediately clear from this problem - - although maps are the most common source of coordinates in the field, do not use even the best large-scale (1:50,000-scale) tactical line maps for precision targeting of modern munitions. Precision munitions, unless laser-guided, need target coordinates measured by DMA in its baseplants or by properly-trained operators of APPS in the field.

The less obvious message, though, holds a culture shock for the mapping community and the combatant in the field. For the first time, the field user with a hand-held GPS receiver can consistently know his position on the battlefield more precisely than the map can position the features of that battlefield. We used to teach the soldier to blame himself for shortcomings in map reading when he couldn't get land navigation or terrain reconnaissance tasks right; now nagging inconsistencies between two authoritative sources of information, the GPS receiver and the map, if not countered by training, will erode the soldier's confidence. This doesn't mean the map isn't good - - people must be trained to recognize and use the powers of both positioning and mapping, and begin to use maps as reliable pictures of the terrain around them.

The section on adjustments in the mapping community discussed the utility of the Landsat Image Map (or LIM) for support of contingency operations. Although every effort will be made to follow interim products like the LIM with traditional products like the tactical line map, our military forces are more likely in the foreseeable future to experience contingency operations in unexpected areas than combat in mature theaters. If we are serious about training as we will fight, we should use LIMs extensively during map-reading training, and we should conduct field exercises of contingency operations with LIMs rather than tactical line maps, even if the latter exist over the exercise area. Frequent contact with products like the LIM will have several benefits for the force - - the unease over having to rely on unfamiliar products will disappear, the force will learn what terrain knowledge it can expect to gain over unfamiliar terrain when operationally committed, and the MC&G community can use feedback from the field to help improve the design of interim products.

The previous section (and the Appendix) also outlined some of the power and applications of simulators and mission rehearsal systems that use terrain data. Combatants will be quick to recognize the cost effectiveness and safety of simulators for certain types and levels of training, as well as opportunities for experimentation not otherwise possible. Simulators should arrive loaded with adequate terrain data sets. Mission rehearsal systems, on the other hand, require real terrain data of the areas of potential operations; commands must communicate needs for such data to DMA or ensure that they have in-house means to assemble the data when required. Once properly loaded or supplied with rapidly-accessible data packages, mission rehearsal systems can serve as bases for intelligence and threat data overlays and clearly will be critical to effective contingency operations.

Since most contingency operations will dictate some measure of "come as you are" mapping support, the U.S. combatant who understands the strengths and limits of the terrain knowledge available to him can make wiser decisions on the battlefield with the assurance that, no matter what, he is still better off than his opponent.

ESTABLISHING REQUIREMENTS

There will never be the resources to map the whole world to the exacting standards demanded for ground combat. Furthermore, the surface of the earth keeps changing, primarily through cultural changes (the influence of man), and must be remapped.

Input from the combatant commands in the form of geographic area requirements for MC&G support is critical if DMA is to properly direct its production and maintenance effort. During the Cold War, the superpower confrontation tended to hold regional issues in check, and the geographic areas of greatest interest and danger to the U.S. remained fairly static; geographic area requirements for MC&G support could be stated on annual or biennial cycles and still present a picture of gradual evolution that allowed relatively stable production programs in DMA. The end of the Cold War and the prospect of a string of regional contingencies in the future, however, has driven DMA to abandon cyclical area requirements and accept new requirements as they emerge.

As currently envisioned, MC&G officers in the commands will interface with staff counterparts, particularly in their commands' planning processes for both operations and exercises, and identify geographic area requirements that should be placed in priority and sent in, as required, to DMA. This paper argues that the line should be shorter and tighter. The status of maps and ongoing map production should be directly available to planners through WWMCCS so that they can do feasibility checks during the earliest stages of planning. A map requirements module in JOPES should assist planners in determining what requirements their plans would place on DMA; once those requirements are validated by the command, with the advice and assistance of the command's MC&G officer, the new or revised requirements should be updated automatically with DMA through WWMCCS.

Even with geographic area requirements identified in priority to DMA, the agency needs input from the Unified Commands to its Country Precedence List. Commands should take this input seriously, as it will influence how much energy DMA puts into preparing MC&G products on a country or region for contingency operations.

Through their MC&G officers and DMA liaison officers, commands can provide input to DMA on anticipated missions or hotspots within countries that can help focus the agency's preparation of Current Operations Packs. Once these packs are prepared, combatants should familiarize themselves with the contents and, where appropriate, exercise with them to work out any difficulties and to develop confidence in the command's ability to execute contingency missions on unfamiliar terrain.

At any time when MC&G support issues become intractable irritants or loom large enough to threaten mission readiness, commands should not hesitate to ask DMA for temporary help from a Command Support Team. These teams can be very helpful in peacetime during OPLAN/CONPLAN preparation and in crisis to assist with preparation for contingency operations.

CAUTION

Through cooperative efforts of DMA, the Services, and the Unified and Specified Commands, U.S. military forces can adapt to their new role as primarily expeditionary forces and arrive on what might have been unfamiliar ground during contingencies with superb terrain knowledge.

There is, however, a potential danger lurking in the shiny promises of technology. A bunker mentality can set in on a commander who lets himself be harnessed to his command post and radio so he is never out of contact; if he doesn't go face to face with his soldiers and subordinate commanders, he might miss the steely resolve or hint of fatigue that could decide tomorrow's battle. Although one cannot see all and know all, there is no substitute for feet on the ground and the "smell of the cordite" to establish the palette with which a talented, experienced commander can color the big picture and make more sound decisions. Even the best maps and three-dimensional computerized terrain graphics, studied in detail before concurring with commitment of coalition engineers to repair and open Sirsenk Airfield in northern Iraq, failed to prepare the author for the actual size of the valley and the maneuver space available for aircraft - - it had to be seen and felt in person.

Map reconnaissance, terrain analysis, and computerized terrain visualization cannot compete with personal reconnaissance in providing a sense of terrain, but remain the next best thing and offer a wealth of terrain knowledge at a fraction of the investment in time, resources, and exposure to danger. The command should use them wisely.

SUMMARY OF RECOMMENDED CHANGES

Technologically, organizationally, and procedurally, the mapping community is adjusting to a changed world environment in which U.S. military forces will be primarily expeditionary in nature, deploying to relatively unfamiliar areas with little advanced warning. Whether or not those forces arrive during contingency operations with an appreciation of the terrain and with the tools and training to quickly learn the ground and effectively employ their combat power will depend, to a large degree, on the pace at which the mapping community and the combatant carry out the recommendations in this paper.

Those recommendations are summarized below, along with the suggested offices or agencies of primary responsibility and cross-references to discussion of the recommendations in this paper.

RESOURCE ALLOCATION

Army, Marine Corps:

- Review allocation rules for field topographic engineering to assure adequate support to joint operations (page 15).

Unified and Specified Commands:

- Be prepared to budget for purchase of multispectral imagery (pages 21, 27, 48).

DMA:

- Program sufficient crisis support resources for continued frequent contingency force deployments (page 6).
- Be prepared to defend production resources against decrements tied to reductions in support of strategic systems (pages 27-28).

ORGANIZATION

Services:

- Develop small Combat Graphics Teams for deployment on contingency operations (pages 29, 53).

MC&G DATA AND PRODUCTS

DMA:

- Accelerate work on military standards for digital MC&G data, particularly those affecting value-adding and coproduction (pages 20, 23, 47).
- Standardize the Landsat Image Map (pages 21, 48).

EQUIPMENT

Army, Marine Corps:

- Equip field topographic engineers with image processing equipment to manipulate multispectral imagery (pages 14, 21-22, 29, 53).
- Equip field topographic engineers with compact NAVSTAR/GPS receivers (page 49).
- Continue development and fielding of DTSS (page 53).
- Pursue downsizing of DTSS and linkage with a digital scanner/printer in a single, compact vehicle (pages 29, 53).

Services:

- Convert from hardcopy to video or digital point positioning data bases in field-deployable precise targeting systems (page 22).
- Continue fielding mapsheet-capable digital scanner/printers (pages 23, 51-52).
- Upgrade communications support of the field topographic engineer (page 29).

Services, USSOCOM, DARPA:

- Continue development of simulation and mission rehearsal systems using terrain data (pages 25-26, 53-54).

TRAINING

Services, Unified and Specified Commands:

- Use the Landsat Image Map (LIM) in training (pages 21, 37, 48).
- Increase use of simulation and mission rehearsal systems using terrain data (pages 25-26, 37-38, 53-54).

Services, DMA:

- Enhance training of the topographic engineer to serve as terrain expert for the field force (page 29).
- Continue to stress need for personal reconnaissance in addition to effective use of MC&G support (page 40).

Unified and Specified Commands:

- *Ensure combatant familiarity with sources of error in map use and* targeting (pages 18-19, 35-36, 45-46).
- Train with Current Operations Packs when available (pages 31, 39, 55).

PROCEDURES

Services:

- Continue research and development to expand field utility of GPS positioning (pages 22, 49-50).
- On receipt of digital scanner/printers, convert map reproducible materials to digital form (pages 24, 52).
- Continue development and fielding of exportable terrain data exploitation packages (page 52).

Services, Unified and Specified Commands, DMA:

- Convert to a map numbering system using NSNs (pages 26, 54-55).
- Introduce barcoding on all standard MC&G products (pages 26, 54-55).

Services, DMA:

- Continue development of standard modules for terrain data exploitation (pages 47, 52).

Unified and Specified Commands:

- Presume U.S. lead for mapping support in any combined operation and organize accordingly (page 15).
- Request Command Support Teams from DMA as required (page 39).

Unified and Specified Commands, JCS:

- Use the mapping status and requirements module in JOPES, when developed, to assess planning options and identify area requirements for mapping (pages 12, 30-31, 38-39).

Unified and Specified Commands, JCS, DMA, State Department:

- Continue initiative to develop and maintain the Country Precedence List, Country Books, Starter Sets, and Current Operations Packs (pages 31, 39, 55-56).

DMA:

- Develop a mapping status and requirements module for JOPES (pages 12, 30-31, 39).
- Initiate new review of optimal balance between war reserve stocks of maps, operational and planning stocks, and surge printing or copying (pages 20, 28).
- Develop a DoD policy on management of multispectral imagery (pages 21, 27, 48).

Federal Agencies with State Department lead:

- Review adequacy of process for placing international mapping requirements on DMA (page 15).

APPENDIX

The following are technical elaboration and justification of selected points made in the basic text:

MAP ERROR

Since before World War II, maps have been created by exploiting the geometry of stereo aerial imagery to remove distortions and by anchoring compilations of features seen in the imagery to a network of control. That basic process, despite tremendous advances in technology in all areas of mapping, remains the foundation of present and projected future mapping. The tools of the imaging, control, and compilation steps of mapping are so precise that the error introduced into a 1:50,000-scale compilation for most features is 50 meters or less[42] (or 1 millimeter, about the width of a mark from a stubby pencil, on the map).

Maps were initially drawn by hand, with technical pens or other tools, to symbolize compiled features in standard ways. Because symbols must be exaggerated from true scale to be legible, some interference between symbols close to each other was inevitable, and symbols had to be displaced from their compiled locations to be legible. Furthermore, some "cartographic license" went into smoothing curves in roads, contours, and other features to make them more pleasing to the eye and to match them with other compiled features like waterways. The additional error introduced through displacement of symbology, on the order of another 50 m in 1:50,000-scale mapping[43] (another pencil mark width), is there to make the map more legible and, frankly, to build the user's confidence in the quality of the map. Advances in technology, through the stages of scribing (scratching the symbols into a coating on film), semi-automated cartography (computer-assisted map drawing), and now true digital cartography (computer-drawn maps), have not reduced the error from symbology displacement; displacement rules and cartographic license have been carefully built into the advanced technology to keep the finished products from looking like they came off a machine.

Because maps must be printed in multiple "impressions" to build up their colors, some displacement of the brown, blue, or green will occur from the black base; this is not considered to contribute significantly to map error because standards for map error revolve around accurate placement of clearly-defined features, which generally appear in the black impression and are thus locked to the grid from which positions are measured.

The final major source of positional error in a map is the user. The user of a 1:50,000-scale map will typically contribute another 50 m in error[44] (or another pencil mark width) through crudeness in the measuring templates used or through inability to estimate precisely between tick marks on the templates. This amount of error, of course, assumes that the user did not subsequently make the classic blunder of giving the resulting coordinates to someone using a map constructed on a different ellipsoid.

All in all, under the best of conditions, a field user might be able to get a coordinate for a clearly-defined feature within 150 m of its true location from a Class A 1:50,000 topographic line map, the largest scale commonly produced to support tactical operations.

DIGITAL MC&G PRODUCTS

The first digital MC&G products entered the inventory to support simulators, trainers, and mission rehearsal systems that could afford fixed installation of the huge computers then required to process terrain data. As computing systems grew in sophistication and got smaller, digital MC&G products moved in to support weapons systems, particularly in the areas of trajectory planning and en route and terminal guidance of munitions. These first digital products were simply digitized from hardcopy sources such as color separations prepared for printing, or even already printed maps, with all the errors inherent in those sources.

Changes in imaging technology, the importance of digital terrain data to America's strategic systems (particularly its cruise missiles), and the promise of heightened production efficiency drove DMA to invest heavily in digital production processes during the 1980's. DMA is converting to a Digital Production System (DPS) in which the only non-digital steps will be the final ones associated with making hardcopy maps. Future production of digital products, then, will be digital from source to product; terrain data can be kept in their true "centerline" positions as derived from imagery, and symbology displacement can disappear from digital databases. This change is fortuitous, for the computing power now becoming available to military forces in the field is prompting calls for production of accurate terrain data with which to populate geographic information systems that will support tactical decisionmaking.

The explosive growth in systems that use terrain data prompted a call by the Joint Requirements Oversight Council (JROC) in 1987 for DMA to take the lead in establishing military standards for digital MC&G data, exploitation packages, and quality and currency assurance. These standards are vital for interoperability of terrain exploitation systems within the U.S. Armed Forces, and will allow the U.S. to take the lead in ensuring interoperability with current and potential allies. To date, DMA has published eleven military specifications (MIL-SPECs) for MC&G products and three military standards (MIL-STDs) on procedures, with a variety still in work,[45] leaving a great deal yet to be accomplished in the area of standardization.

MULTISPECTRAL IMAGERY

Multispectral imagery (MSI) consists of images of the same area taken within different spectral ranges; the imagery allows identification of material through varying reflectance, or the "signature" of the material in the spectral ranges. The imagery is very useful in analyses to classify surface materials such as soil, road surfaces, and vegetation; the resulting terrain information can then be used in original or update mapping and in terrain analyses such as mobility predictions or site selection. MSI can also be used to investigate ice states, sea states, and shallow bathymetry.

Landsat is the U.S. civil imaging system; its satellites have a revisit time of 16 days (i.e. any portion of the globe can be imaged from over-head within a 16-day period), and DoD can override civil tasking of the system to meet its requirements during crises. Although the U.S. military has also purchased MSI from France's SPOT Image Corporation, DoD of course has no override authority over SPOT. This greatly reduces the potential value of this higher-resolution system for crisis support. MSI has other drawbacks in crisis situations; its bands that are useful for reconstructing true-color images of the earth, unfortunately, have to lie in the visible spectrum and thus are limited by cloud cover. Unanticipated crises occurring at the wrong time of the year in seasonally cloud-covered areas could wipe out MSI as an imagery source, as nearly occurred for Haiti during the 1991 noncombatant evacuation operations.

Systematic management of DoD's tasking of the Landsat system for imagery and of its purchases of existing MSI, along with an archive or tracking system for hardcopy and softcopy MSI once acquired within DoD, would assist greatly in ensuring the availability of required MSI in crises. Such management would also allow DoD to take maximum advantage, fully within legal guidelines, of its purchases of materials over which stringent rules exist on duplication. DMA is charged with administering DoD's MSI acquisition program, but has limited its role to serving as a purchasing agent (and delivery conduit) for MSI purchased by any DoD activity and is only now discussing whether it should promulgate an MSI policy.[46] Even within the Army, there is no program to manage the procurement of MSI data.[47]

Despite the systemic weaknesses in DoD's current MSI data program, good use is being made of the imagery that is obtained. The Landsat Image Map (LIM), along with softcopy MSI, is now emerging as an interim product for contingency support and as a support product for exercises of contingency support. The DMA Systems Center is prototyping 1:100,000-scale LIMs over five sites in the continental U.S. (Ft Rucker, Ft Bragg, Ft Hood, Camp Pendleton, and Camp LeJeune) with a newly-acquired in-house production capability for LIMs.

DMA expects the LIM, when finalized as a quick-response product for crisis support, to be orthorectified (all imagery brought to its true geographic position, removing any displacement caused by the imaging system or relief); it will incorporate elevation data, time permitting, where the data are available. The image will be reconstructed from the spectral bands to look like true color. Three levels of the LIM are projected now; the lowest level would simply be rectified imagery with a grid, the intermediate level would add enhanced road networks and names, and the highest level would incorporate SPOT imagery for sharpness and add contours (using the best between available digital terrain elevation data or cartographic sources). With the use of SPOT imagery, the highest-level LIM could even be produced at 1:50,000 scale and still give excellent results.

NAVSTAR/GPS

By 1993, the Navigation System Using Time and Ranging / Global Positioning System (NAVSTAR/GPS) will permit passive, continuous, global three-dimensional self-location and navigation to a precision of 16 meters (spherical) or 10 meters (circular) using the precise positioning and navigation service (PPS) available to the U.S. military and its allies; the general public will have the standard positioning service (SPS), which yields about 100-meter positioning accuracy.

Hand-held NAVSTAR/GPS receivers revolutionized positioning in the 1991 Gulf War at the same time that platform receivers had their first combat applications on MH-53 Pave Low helicopters, F-16 fighters, B-52 bombers, and Navy stand-off land attack missiles (SLAM).[48] NAVSTAR/GPS receivers adapted with transmitter systems have also been used in tracking critical logistics,[49] and in some circumstances might be useful in command and control of friendly forces.

It goes without saying that the topographic engineer, who has his own navigation needs on the battlefield but also must stand on the terrain to gain a personal appreciation and provide spot-check ground-truth validation of terrain data collected by other means, should be equipped with compact NAVSTAR/GPS receivers.

Current procedures are for a soldier to punch a button on his hand-held NAVSTAR/GPS receiver to get a coordinate, which he then transfers to his map to locate himself and see what is around him. Clearly, technology should allow "slaving" of a map display to the positioning receiver.

This is not a unique idea, as evidenced by the following projection for the future:

> "A solitary, strangely-helmeted figure (. . .) spots 15 enemy armored vehicles (. . .) He quickly flips down his helmet-mounted computer display over one eye and consults a Global Positioning System indicator to determine his location within 20 feet. (. . .) he scans across a digital depiction, a virtual image, of the area terrain. Then using his thumb to operate a miniature joystick, he pinpoints a newly-constructed bridge that spans a small ravine and further notes an overhanging, boulder-studded cliff just beyond the bridge. He deftly moves his thumb to mark these potential target areas on the digitized terrain map. (. . .) This is a conceptual view for the employment of the Soldier's Computer that is expected to become operational by 1998. (. . .) The Soldier's Computer is a central element of the Soldier Command, Control, and Communication (C3) program, a U.S. Army Communications-Electronics Command (CECOM) program that will integrate the individual soldier into an automated C3 system."[50]

NAVSTAR/GPS offers significant military opportunities beyond creative uses of compact positioning systems. Positioning within three meters is feasible now with GPS differential surveying,[51] even for dynamic platforms such as helicopter gunships or vessels involved in coastal bathymetry, dredging, and naval gunfire. Control extended into artillery positions by GPS differential surveying would be quick and precise. With additional research and development, GPS could yield 10 cm accuracy in positioning of a moving platform;[52] this would be immediately useful for the military in precision dredging operations rather than in any currently-conceived combat applications, but technical feasibility will inevitably spawn ideas for application, such as precision gunfire from roving combat vehicles under adverse weather conditions.

TOPOGRAPHIC INFORMATION EXTRACTION SYSTEM (TIES)

The U.S. Army Topographic Engineer Center has the TIES in 6.2 development. TIES consists of an Image Digitizing System (IDS), with Intergraph scanner, and a Digital Stereo Photogrammetric Workstation (DSPW), a General Dynamics component. TIES accepts control data and either hardcopy or softcopy imagery as inputs; it can then classify surface materials and position features for product generation or database population.

DIGITAL SCANNING AND PRINTING

Digital scanner/printers are able to reproduce additional copies of existing color-coded products quickly, generate corrected or enhanced copies, and also provide output from ongoing compilation. By being scalable, these devices bypass the camera for scale-change, saving time and retaining quality otherwise lost in camera steps.[53] The U.S. military's initial effort to apply digital scanning and printing technology to mapping was the Army's program to develop a Quick-Response Multicolor Printer (QRMP). The performance requirements were very stringent (e.g. 600x600 dots per inch, dpi, resolution), and a long and underfunded developmental effort with the Xerox Corp, although promising, was eventually terminated when commercial technology offered less-capable, but usable, systems at much less cost. The current focus is on an off-the-shelf bubble-jet printer, a large-format Canon flat-bed machine that can make 10 full-size color copies per hour, with 400x400 dpi resolution, at a cost of about $12 per copy. The Army had three of these machines in use following Operations Desert Shield/Storm, and is considering putting one in each topographic engineering battalion. A less cumbersome and expensive alternative, particularly for use in contingency operations, might be a smaller-format (11" x 17") Canon bubble-jet printer that is still fully digital, allowing it to copy directly, generate digital files, or print from digital files. The future for field use, however, probably belongs to electrostatic scanner/printers. 3-M Corporation now has an electrostatic printer on the market that combines a small footprint, ruggedness, and low cost (approximately $100,000 each); the printer can make 80 full-color, full-sized maps per hour at a resolution of 400x400 dpi and a cost per map of about $3.00.[54] This technology, developed for making custom signs for sides of trucks, is very competitive with offset printing in mapsheet cost and clearly has the edge for quick response.

REPROMAT SCANNING AND RECONSTRUCTION

Scanning repromat (a simple binary, or one-bit, high-resolution scan would do the job) could reduce a repromat library to a pile of digits that could be easily copied, carried around, and turned back into a transparency on a digital printer or directly into a press plate on a laser platemaker. The same output procedure could be used, perhaps with some loss in map quality, with a compressed form of the Arc-Digitized Raster Graphic (ADRG) currently being developed by DMA to meet the Army's stated need for a 4-bit electronic map.

TERRAIN DATA EXPLOITATION SYSTEMS

The Program Executive Office -- Command and Control Systems (PEOCCS) is integrating digital map backgrounds and line-of-sight analyses from digital terrain elevation data into the Army Command and Control System (ACCS). ACCS consists of the following nodes: All Source Analysis System (ASAS), Advanced Field Artillery Tactical Data System (AFATDS), Maneuver Control System (MCS), Combat Service Support Control System (CSSCS), and Forward Area Air Defense Command, Control, and Intelligence (FAADC2I). For those systems supporting planning and synchronization of combat operations, ACCS would provide additional terrain evaluation and three-dimensional visualization. Through combined efforts of PEO-CCS, TEC, the U.S. Army Waterways Experiment Station (WES), Project Manager Operations Tactical Data Systems (PM OPTADS), the Combined Arms Center (CAC), U.S. Army Engineer School (USAES), and various support contractors, work is progressing on a standard Terrain Evaluation Module (TEM) that should bring exploitation of digital MC&G data to a wide variety of Army users.[55]

The ongoing ACCS development of electronic map capabilities saw its first combat application in Operation Desert Storm. Terrain modeling, analysis, and visualization were also successfully used in combat during the Gulf War in other systems. The Condensed Army Mobility Modeling System (CAMMS) and TerraBase (software packages developed by WES and the U.S. Military Academy, respectively, to manipulate digital terrain data) were used in Desert Shield/Storm by the prototype Digital Topographic Support System (DTSS) and U.S. Forces Command's (USFORSCOM's) Automated Intelligence Support System (FAISS), an advanced microcomputer system replacing the MICROFIX system Army-wide.

The DTSS is to be the basic tool for automation of terrain analysis in support of the ASAS (part of the ACCS, discussed previously) and, through ASAS, operational decisions in general. DTSS enters Initial Operational Test and Evaluation (IOT&E) in 1992, continuing to work against a projected First Unit Equipped (FUE) date of fourth quarter FY 93.[56] It now appears that only 22 DTSS may be acquired, limiting fielding to corps level, with efforts to push data forward electronically for exploitation at maneuver brigade. The concept of using exportable data exploitation packages at lower levels not equipped with DTSS or provided with organic terrain analysts was validated in 1990 during the Army's REFORGER exercises in Germany, when the Digital Topographic Enhancement Program (DTEP) successfully provided staff and commanders at brigade level with rapid two- and three-dimensional tactical decision aids, maps, and terrain views.

Technology has progressed to the point that the next step should be radical downsizing of DTSS and direct linkage with a digital scanner/printer so that softcopy imagery and graphics, or scannable hardcopy, can be taken in, controlled, value-added, manipulated, and turned into softcopy or hardcopy combat graphics in a compact vehicle like the High Mobility Multi-purpose Wheeled Vehicle (HMMWV). A Combat Graphics Team of several soldiers equipped with such a vehicle should accompany every expeditionary deployment of U.S. land forces; such teams could be configured from organic topographic engineering assets at corps or division level.

SIMULATION SYSTEMS

Odin, under development by DARPA, links intelligence data, order of battle, and friendly force data with vehicle dynamics and electronic terrain data to display vehicles in a real-time simulation with two-dimensional map display or three-dimensional "out-of-the-window" battle representation.[57] The Battle of 73 Easting, an engagement during the Gulf War between the 2nd Armored Cavalry Regiment and the Iraqi Republican Guards, is the first complete engagement modeled in Odin. Future upgrades to Odin will allow interruption of the battle to alter equipment or tactics to play out options to the battles.

Other key simulation systems using digital terrain data include Program Manager Training Devices' (PM- TRADE's) Close Combat Tactical Trainer (CCTT), PM-TRADE's Battlefield Distributed Simulation-Development (BDS-D), CECOM's Electronic Sandtable, CECOM's Multisensor Aided Targeting (MSAT)/Smart Weapons Operability Enhancements (SWOE), National Simulation Center's Brigade/Battalion Battle Simulation (BBS), U.S. Army Training and Doctrine Command's (TRADOC's) Battlefield Planning System (BPS), National Simulation Center's Army Training Battle Simulation System (ARTBASS), TRADOC's Combined Arms and Support Task Force Evaluation Model (CASTFOREM), Lawrence Livermore National Laboratories' (LLNL's) Janus, the Corps Battle Simulation (CBS) - formerly Joint Exercise Support System (JESS), LLNL's Urban Combat Computer-Assisted Training System (UCCATS), and USSOCOM's Special Operations Forces Aircrew Training System (SOF-ATS).[58] The inescapable conclusion from this listing is that simulation systems using terrain data are big business.

Simulation systems with terrain data are useful in training, analysis, war games, and models, offering results at a fraction of the cost of the real thing and with the potential for risk-free maneuvers at the edge of established performance envelopes.

BARCODING OF MC&G PRODUCTS

The mapping community has been slow to apply barcoding technology or convert to standardized stock numbers, like National Stock Numbers (NSNs), that would be necessary with barcodes. Part of the resistance has come from nostalgia over DMA's unique stock numbering system and from reluctance to make it easy for maps to escape from a stovepiped distribution system within the MC&G and intelligence communities. Experience during the Gulf War with a virtual in-theater breakdown of retail map distribution, with division G-2s making personal trips to go find maps, suggests that it is now time to make a wholesale conversion to NSNs, printed with barcodes on individual mapsheets (not just on labels for packages of maps) and on CD-ROM discs, magnetic media, and their packaging. If this precipitates the long-feared move of maps into logistics channels, so much the better.

MAPPING SUPPORT OF CRISES

DMA has initiated a Country Precedence List and plans to develop Country Books, Starter Sets, and Current Operations Packs.

The Country Precedence List, the only part of this adjustment of DMA's crisis action system listed in the draft for the new MOP-31, is a master compilation, in order of likelihood due to current events, of countries or regions in which U.S. military forces might be employed. DMA developed the first list, published on 30 September 1991, with input from the unified and specified commands, the State Department (which has responsibilities to initiate noncombatant evacuations), and the intelligence community (through the US Foreign Intelligence Requirements Categories and Priorities, or FIRCAP, listing). DMA expects to revise the Country Precedence List every six months, or more frequently if required, with annual concurrence of the Chairman, JCS. As clear evidence of the value of a document that keeps a finger on the pulse of developing situations that might lead to military operations, JCS adapted the first Country Precedence List for use as a table in the new JSCP.

In response to the Country Precedence List, DMA plans to link the standing area requirements for standard products and its own holdings to develop a Country Book for each country on the Country Precedence List; the Country Book will identify all standing requirements, available MC&G source materials, and host nation MC&G production capabilities, and will list the contents of the Starter Set.

DMA would then pull together a minimal country data base, or Starter Set, of finished products or sources from which low-priority products could be made; in essence, the Starter Set would get DMA a jump on product initiation time for crises.

Based on input from CINCs of likely missions and focused geographic areas (hotspots) within countries on the Country Precedence List, DMA will prepare Current Operations Packs to support short-term requirements for mission planning, mission rehearsal, and the initial states of execution of military operations.

In the event of crisis situations confirmed by the Director for Operations, J-3, Joint Staff, the priority system in MOP-31 would be waived, as necessary, to allow DMA maximum flexibility to respond to the crises.[59]

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